TOWARD A NEW PARADIGM FOR AIRBORNE SURVEILLANCE RADAR

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OUTLINE

1. Introduction
2. Earth-centered Radar Processing
3. Active-Testing Surveillance Systems
4. Conclusion

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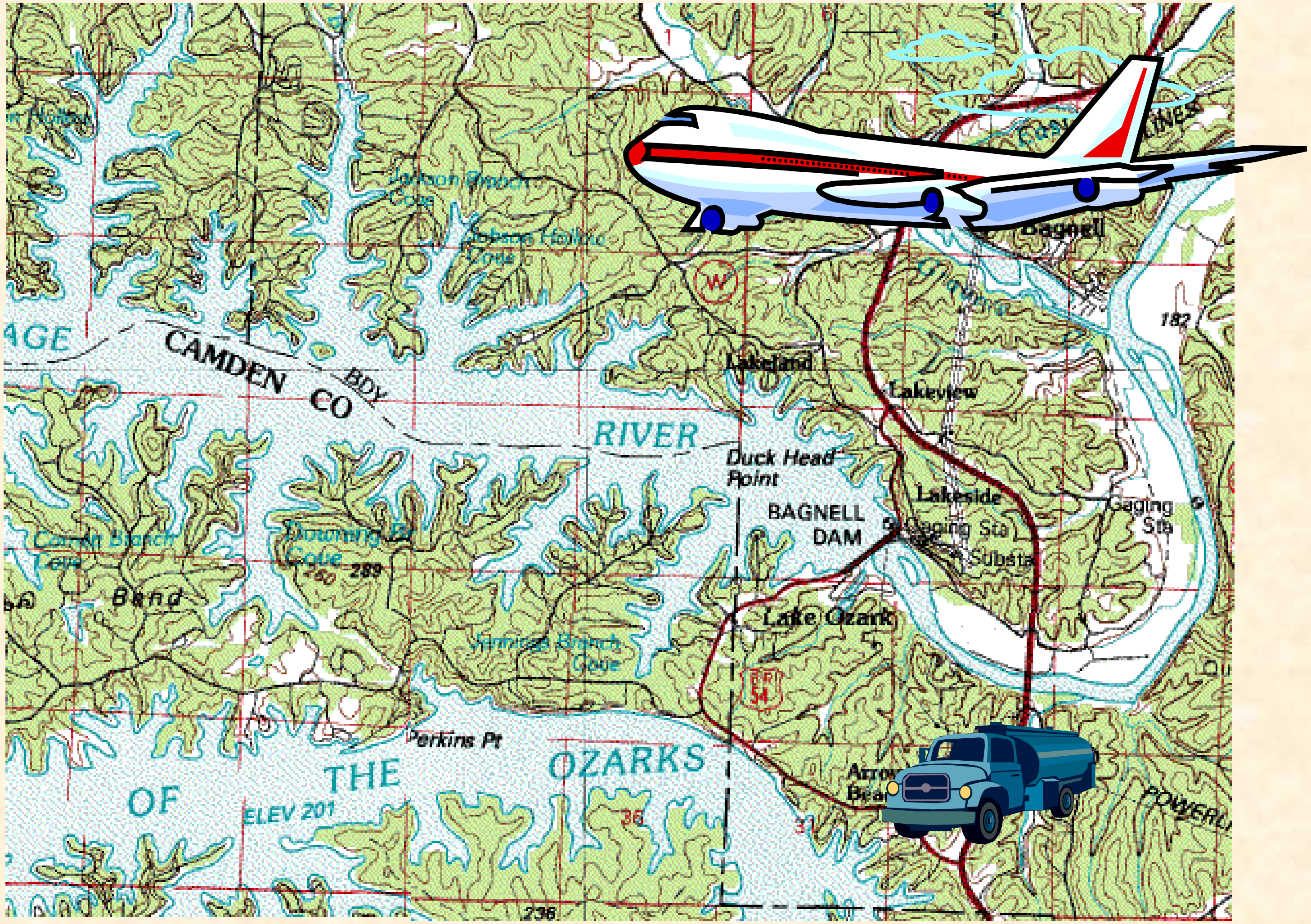
CONTEXT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CONTEXT

- Airborne multisensor pulse-Doppler surveillance radar
- Ground moving targets (GMTI)
- Multiple targets
- Geographical side information (GIS)
- Platform side information (GPS, INS)

Today’s presentation: alternative processing strategies
made possible by confluence of enabling technologies

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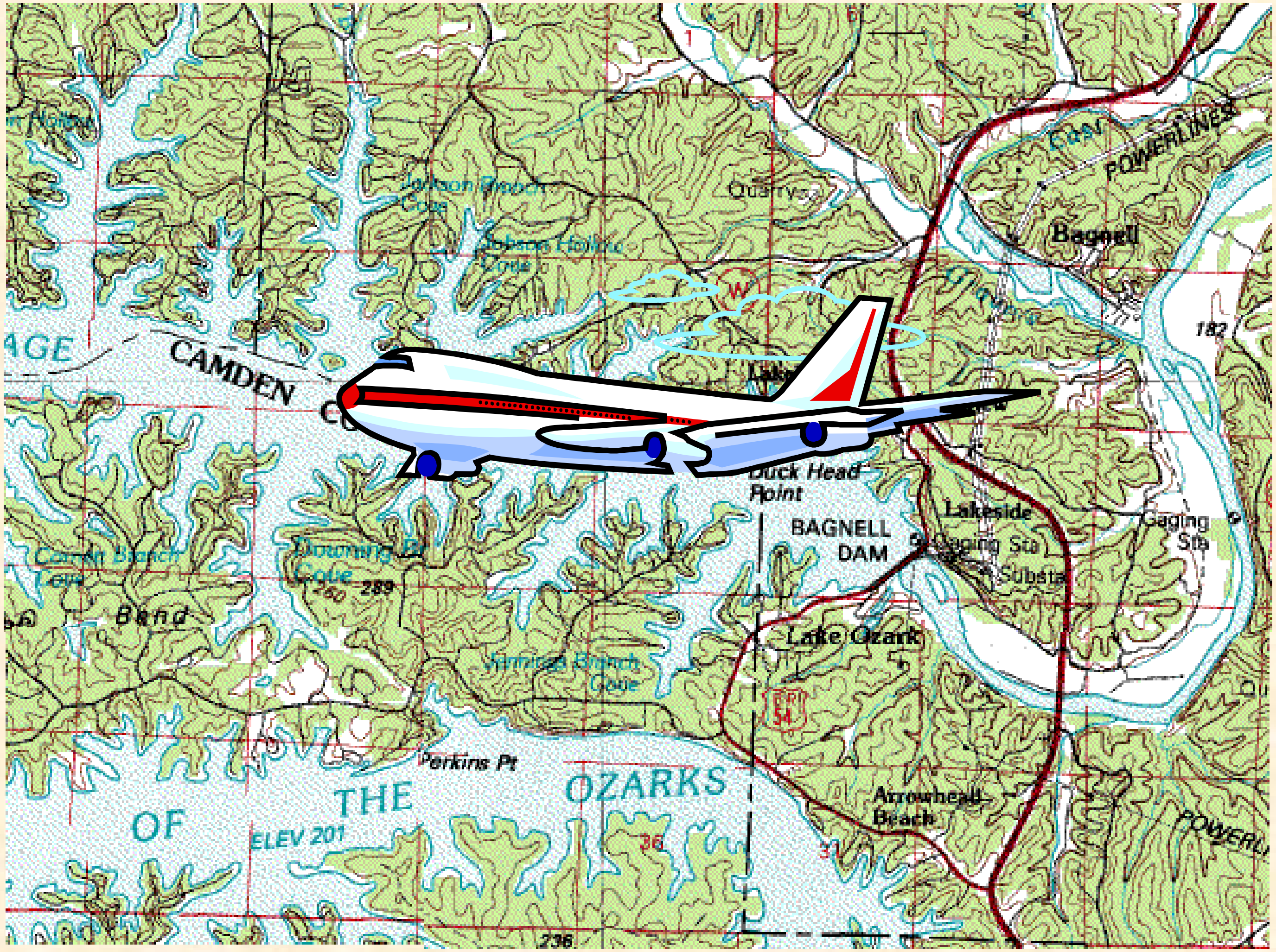
PLATFORM-CENTERED RADAR PROCESSING

A typical airborne radar system collects data and performs statistical inference in the platform-centered coordinates of range, Doppler, and angle

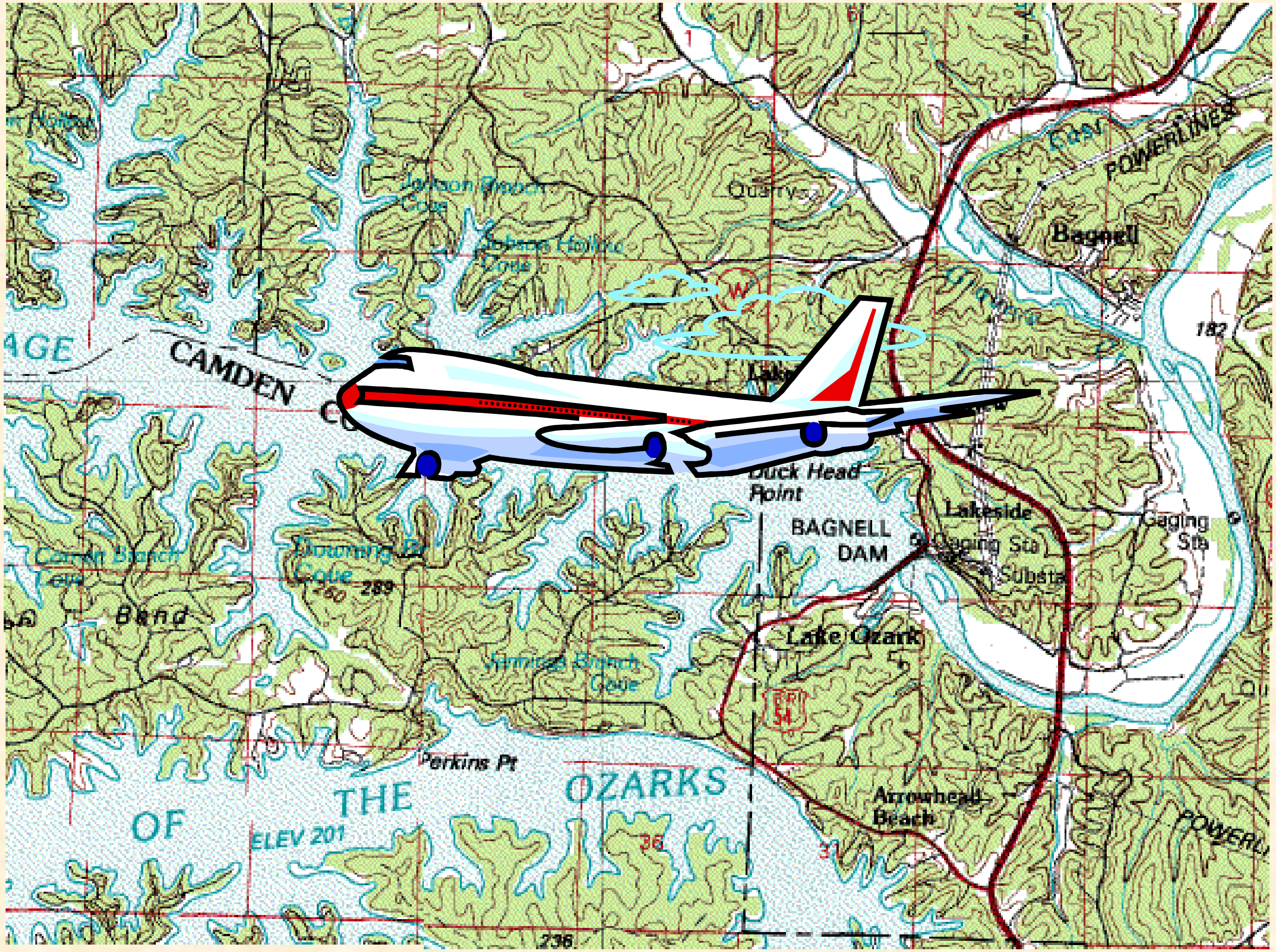
PLATFORM-CENTERED RADAR PROCESSING



EARTH-CENTERED RADAR PROCESSING

We propose the consideration and evaluation of radar systems which collect data and perform statistical inference in the geographic coordinates of latitude and longitude (or equivalent).

EARTH-CENTERED RADAR PROCESSING



EARTH-CENTERED PROCESSING: ADVANTAGES

- Geographical coordinates are intrinsic
- Geographical coordinates are invariant
- Facilitates multiple measurements and look angles
- Facilitates sensor fusion

GEOGRAPHICAL COORDINATES ARE INTRINSIC

What is the mission?

- Synthetic aperture radar (SAR) imaging
- Target detection
- Target tracking

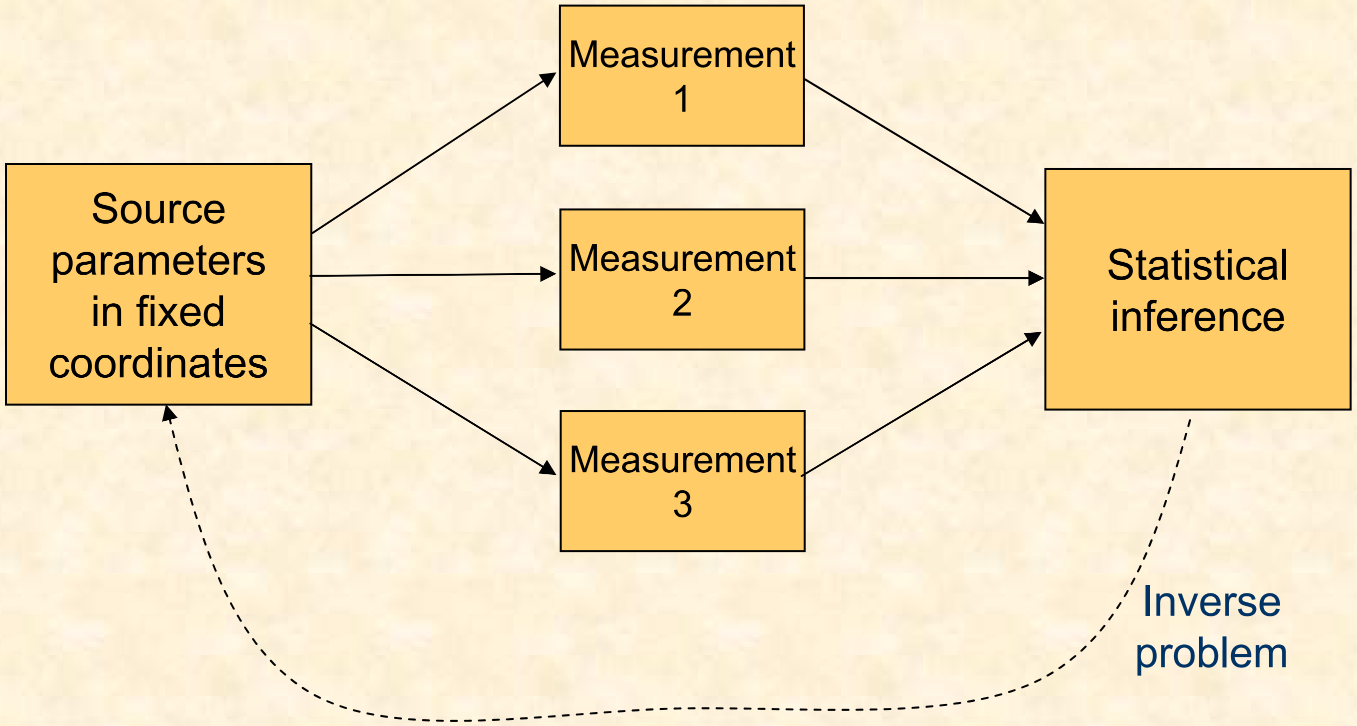
The natural coordinates of the <u>object of surveillance</u> are fixed geographically.

GEOGRAPHICAL COORDINATES ARE INVARIANT

- The local geography is not going to change during the surveillance mission.

- Radar platform position, velocity, and orientation are changing constantly.

MULTIPLE MEASUREMENTS AND LOOK ANGLES



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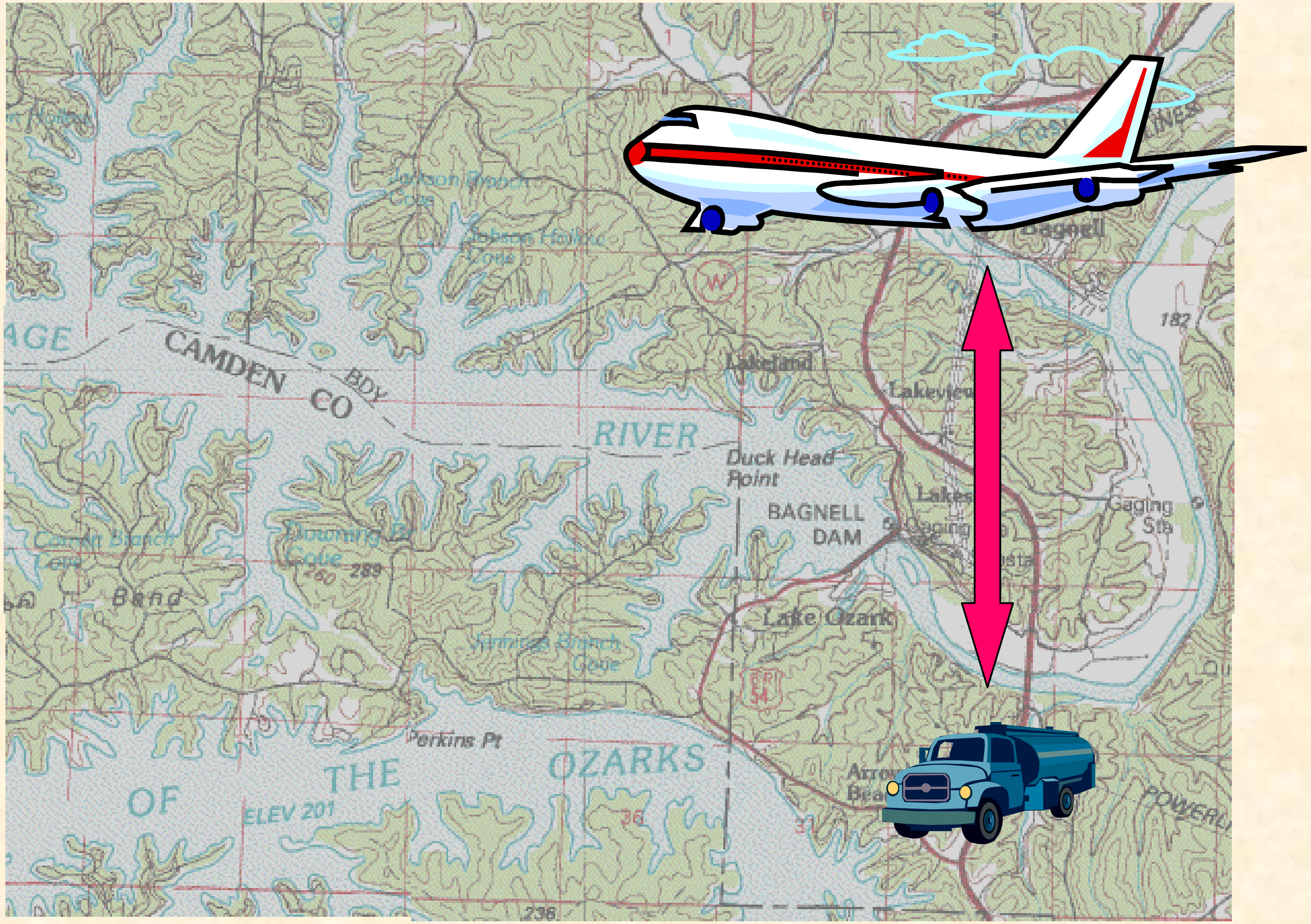

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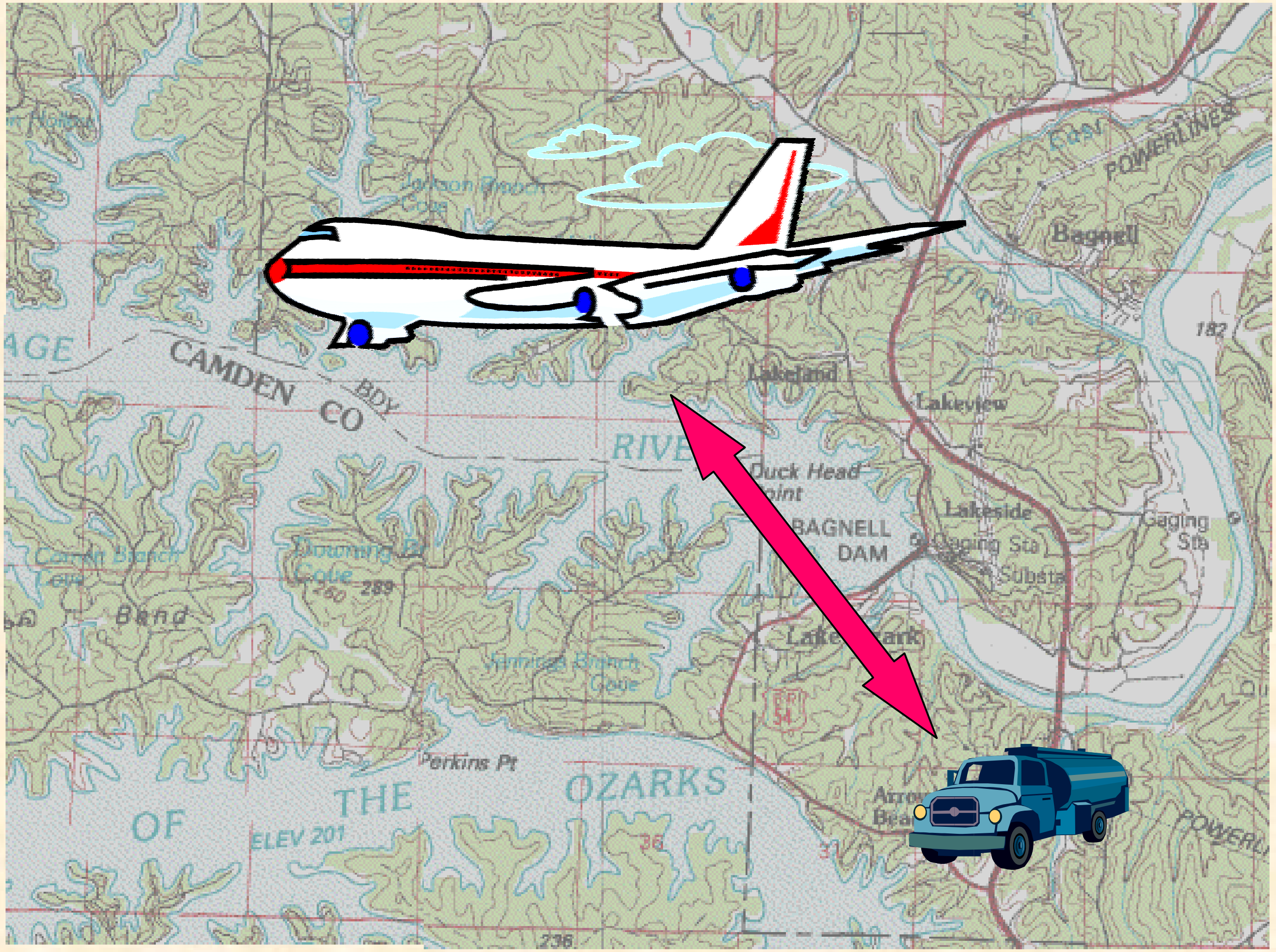

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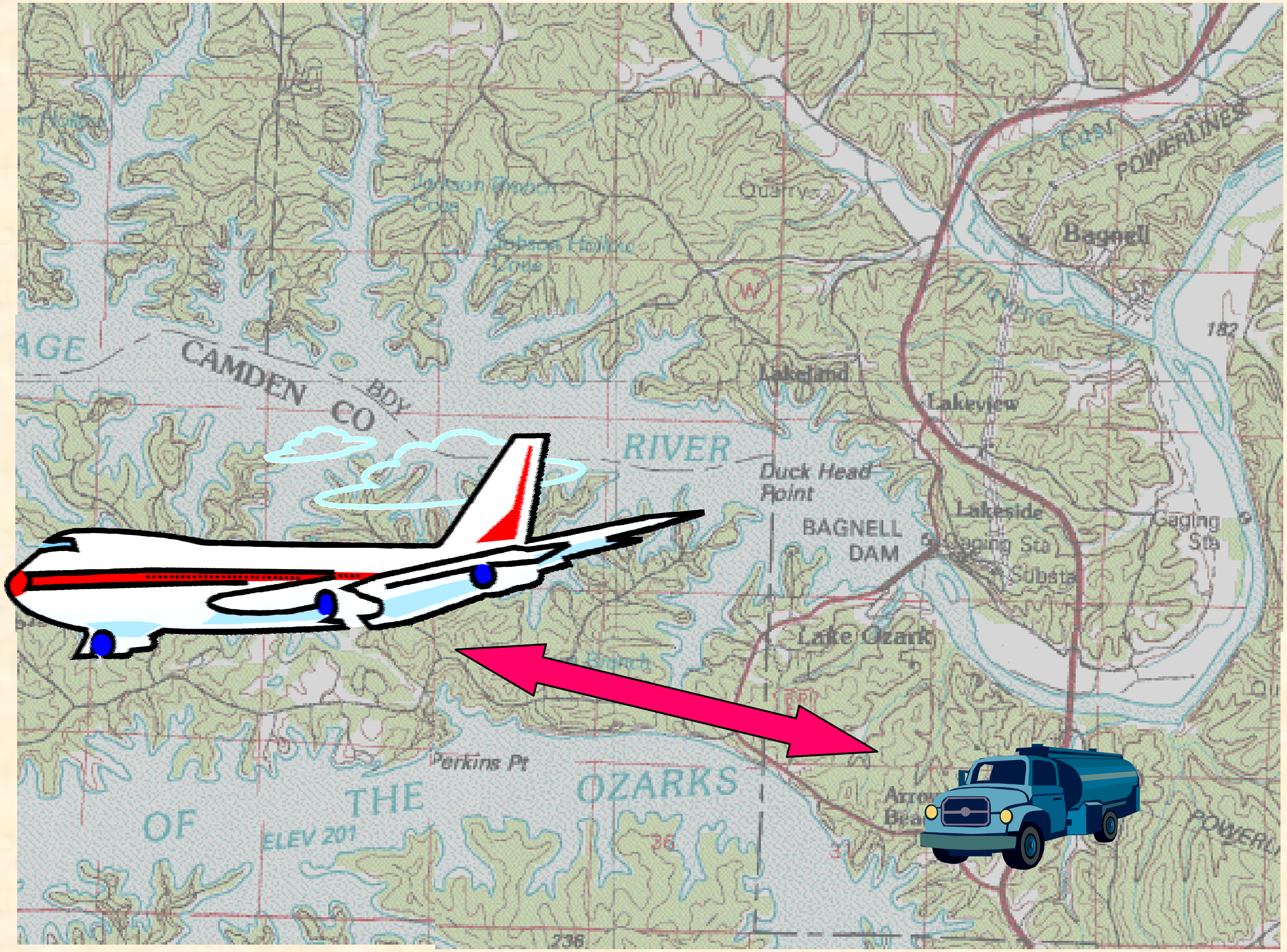
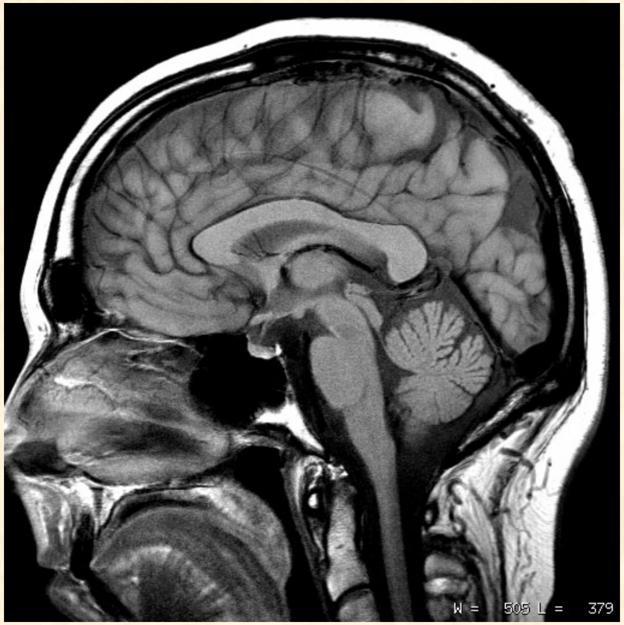


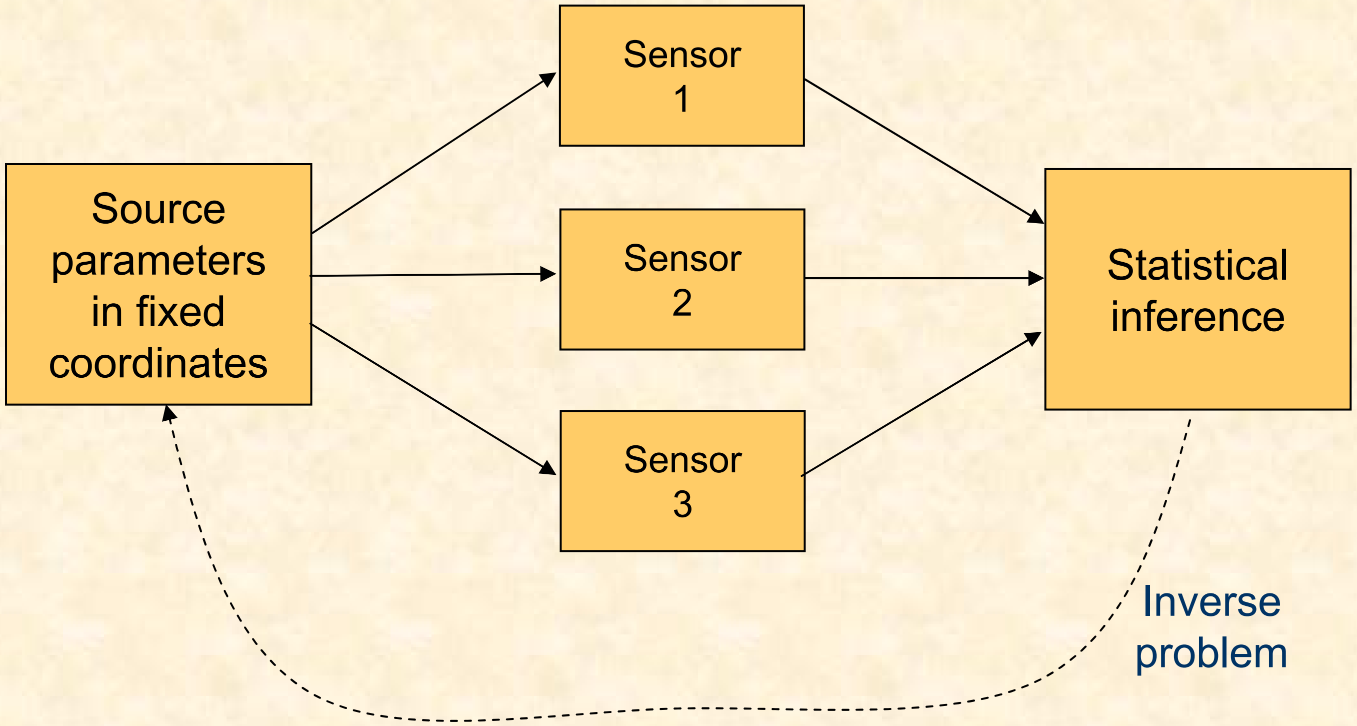
MULTIPLE MEASUREMENTS AND LOOK ANGLES

In this respect, airborne surveillance has much in common with medical imaging: both are problems of remote sensing.

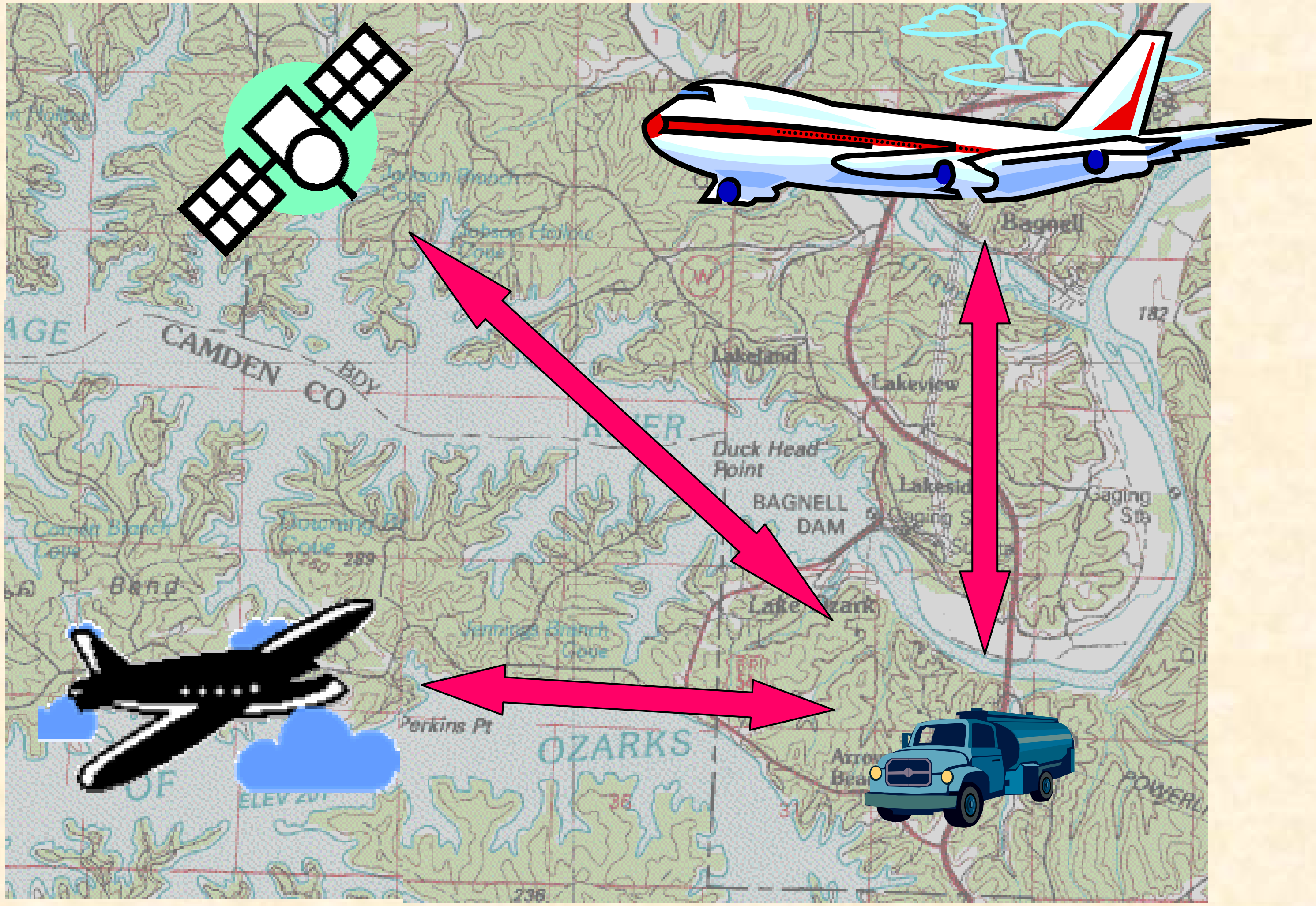


Images courtesy of NASA and GE Medical Systems

SENSOR FUSION



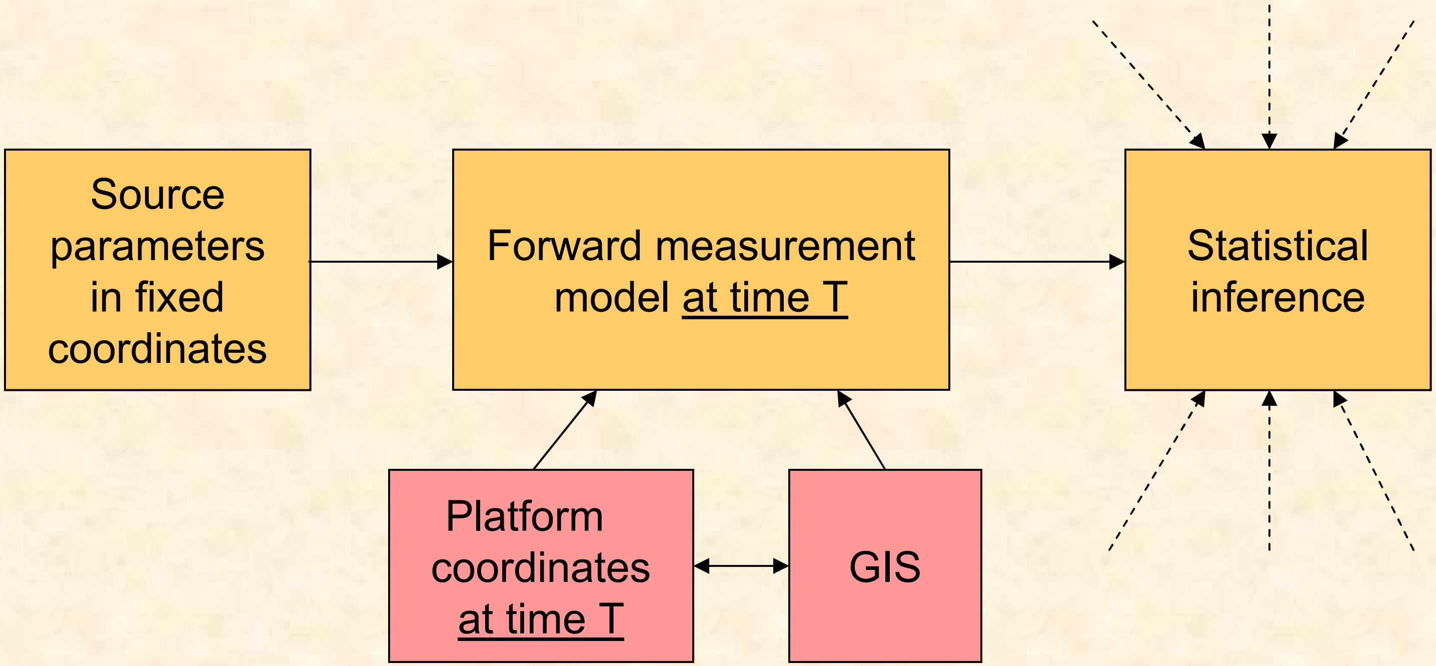
SENSOR FUSION



EARTH-CENTERED PROCESSING: DISADVANTAGES

- Runs counter to 50 years of tradition
- Loss of mathematical structure (FFT, SMI, e.g.)
- Joint calibration of radar + geography
- Computational complexity

THE BIGGEST COMPUTATIONAL PROBLEM



The forward measurement model must be computed for every T

ENABLING TECHNOLOGIES

- Tightly coupled navigation (GPS+INS)
- Geographical information systems (GIS)
- Commodity graphics engines
- Real-time rendering software
- Flight simulators / radar simulators

FLIGHT SIMULATORS (EXAMPLE)

Image courtesy of fscene.com

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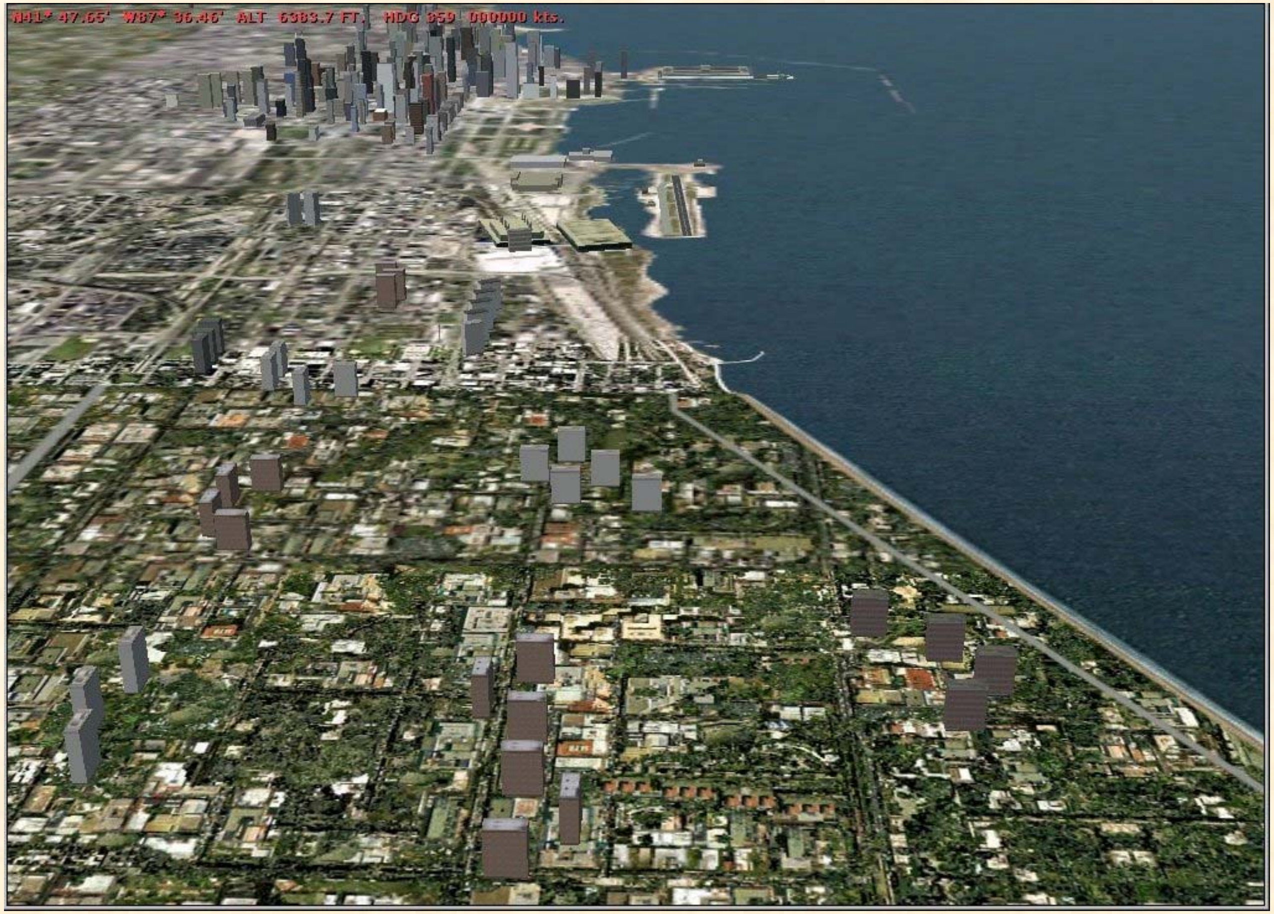

Image courtesy of fscene.com

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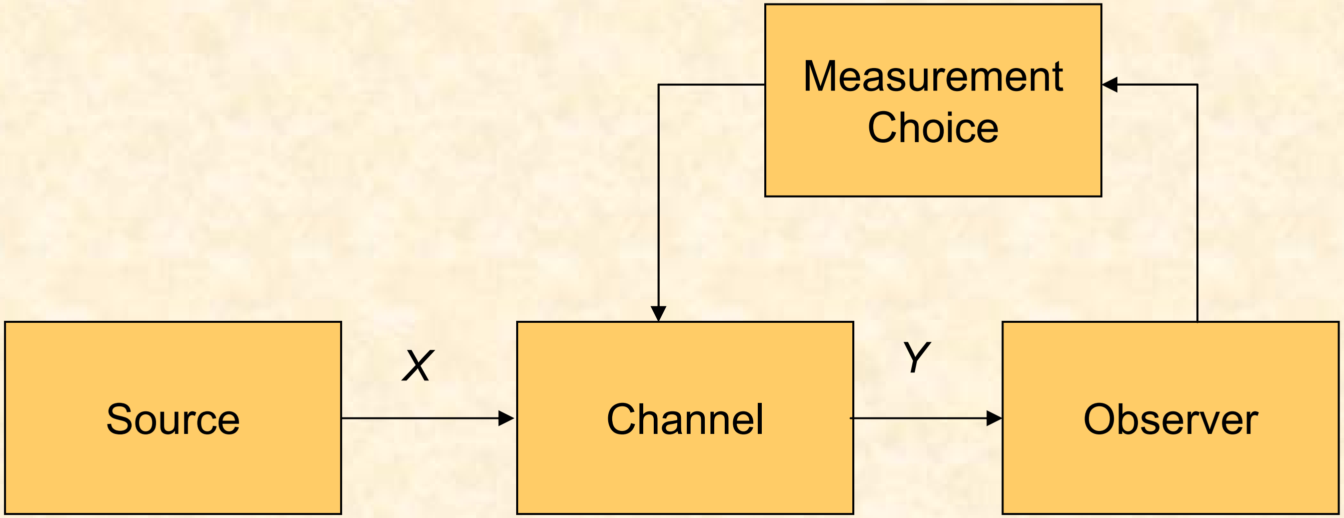
ACTIVE-TESTING SURVEILLANCE SYSTEM



A communication system in the usual information-theoretic sense, with the added feature that the channel can be manipulated by the observer.

GENERAL APPROACH

The goal of a surveillance system is to minimize the entropy of the posterior distribution of the source vector X.

- Entropy definition:

$$H(X) = -\sum_{x} p_X(x) \log_2 p_X(x)$$

- Conditional entropy definition:

$$\begin{aligned} H(X|Y) &= -\sum_{y} p_Y(y) \sum_{x} p_{X|Y}(x|y) \log p_{X|Y}(x|y) \\ &= -\sum_{y} \sum_{x} p_{XY}(x,y) \log p_{X|Y}(x|y) \end{aligned}$$

SINGLE-MEASUREMENT STRATEGY

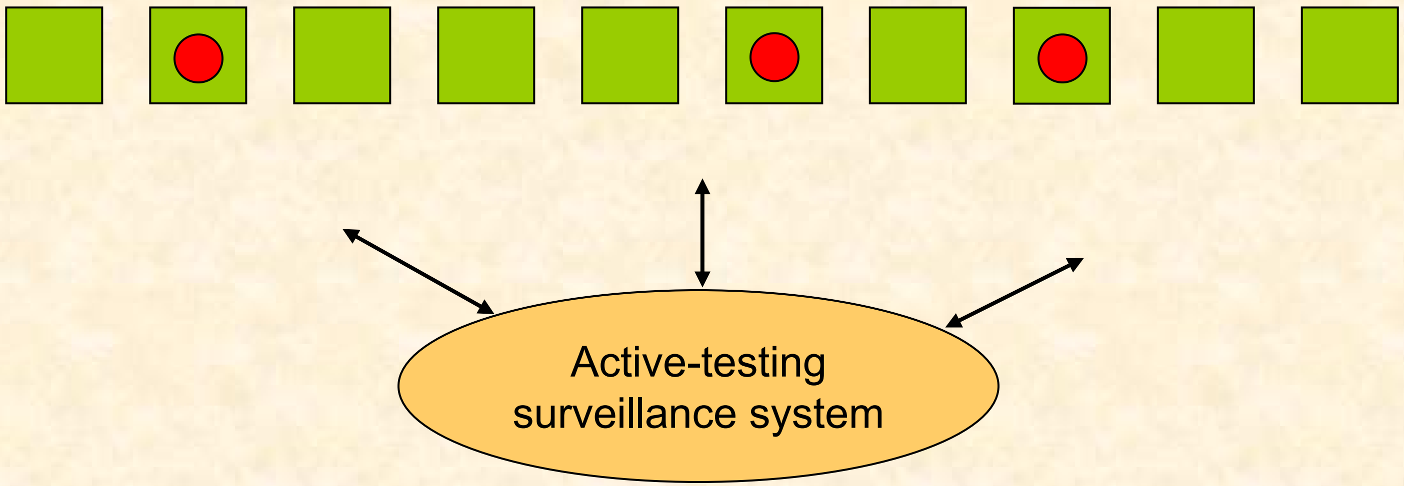
Choose that measurement which maximizes the mutual information I(X,Y)

- Mutual information definition:

$$
\begin{aligned}
I(X,Y) &= H(X) - H(X|Y) \\
&= H(Y) - H(Y|X)
\end{aligned}
$$

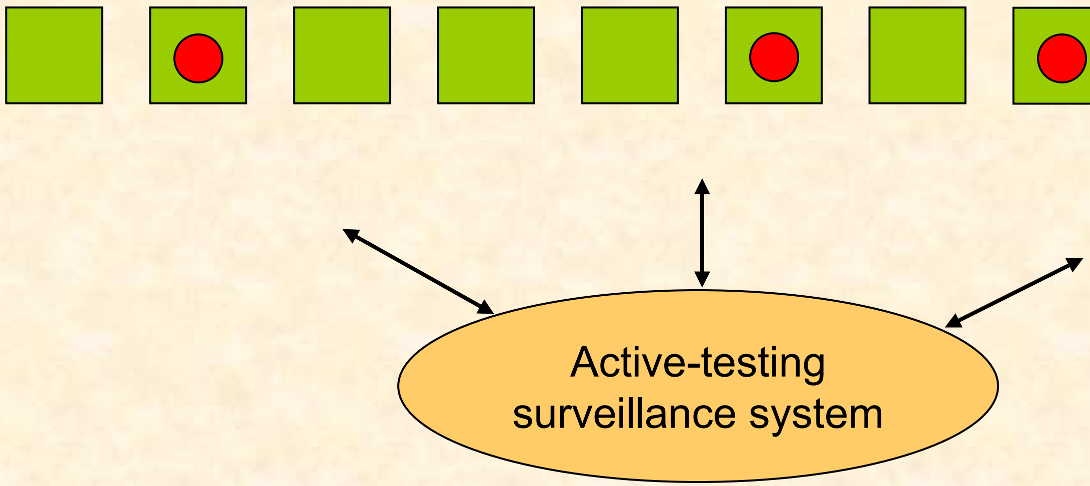
Repeated measurements: maximizing *I(X,Y)* at each step seems obvious and intuitive, but is “greedy” and may not be globally optimal.

MULTIPLE TARGET DETECTION SCENARIO



- N independent cells (ground patches, e.g.)
- Each cell defines a binary hypothesis testing problem
- Divergence between H0 and H1 depends on transmitted energy

FINITE-ENERGY CONSTRAINT

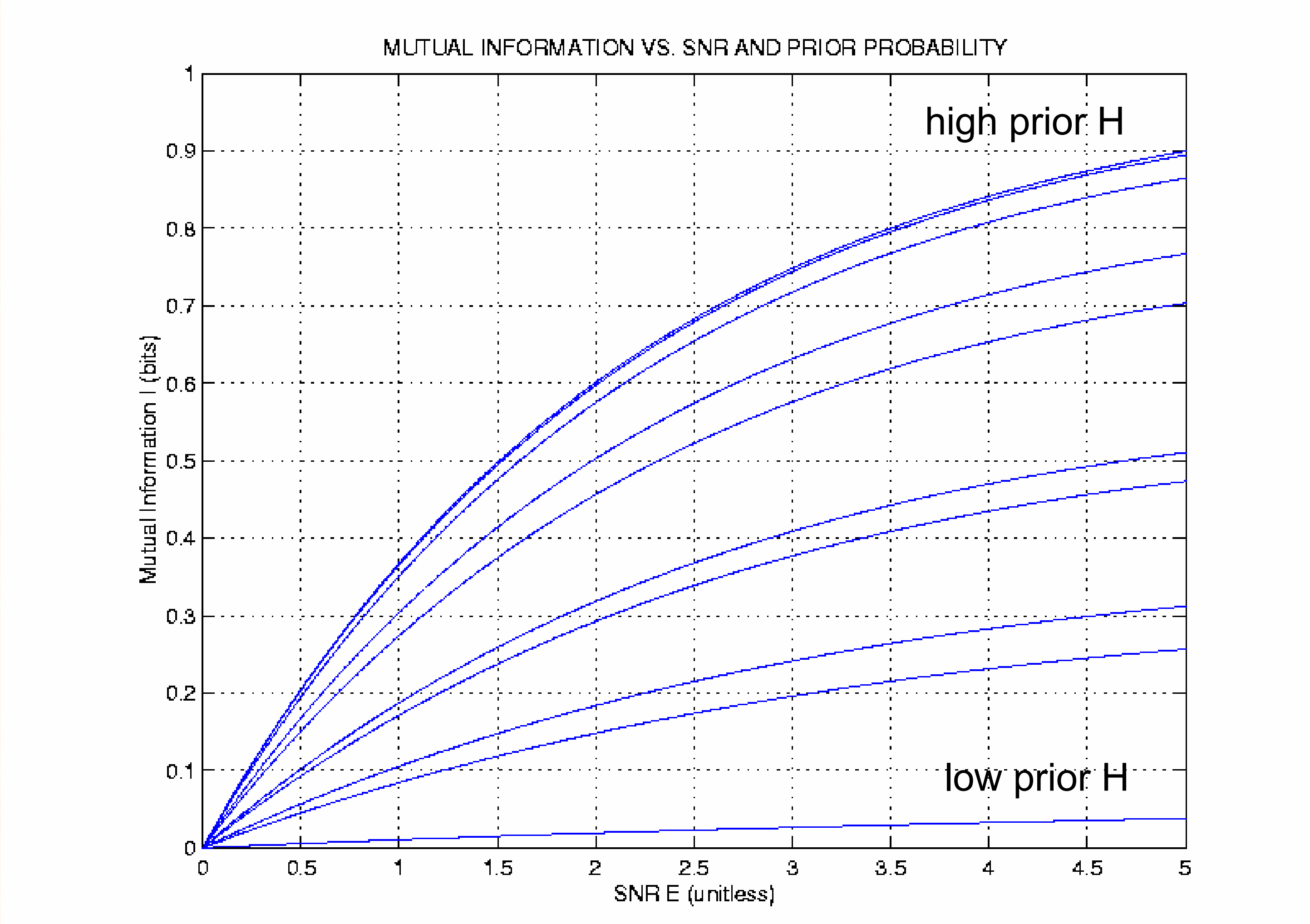


$$\sum_{i=1}^{N} E_i = E$$

The mutual information between each cell and the surveillance system is an increasing function of illumination energy E_i

→ What is the optimum partition of the available energy E?

FAMILY OF I(X,Y) vs. SNR CURVES



OPTIMIZATION OF ENERGY PARTITION

- Optimization problem:

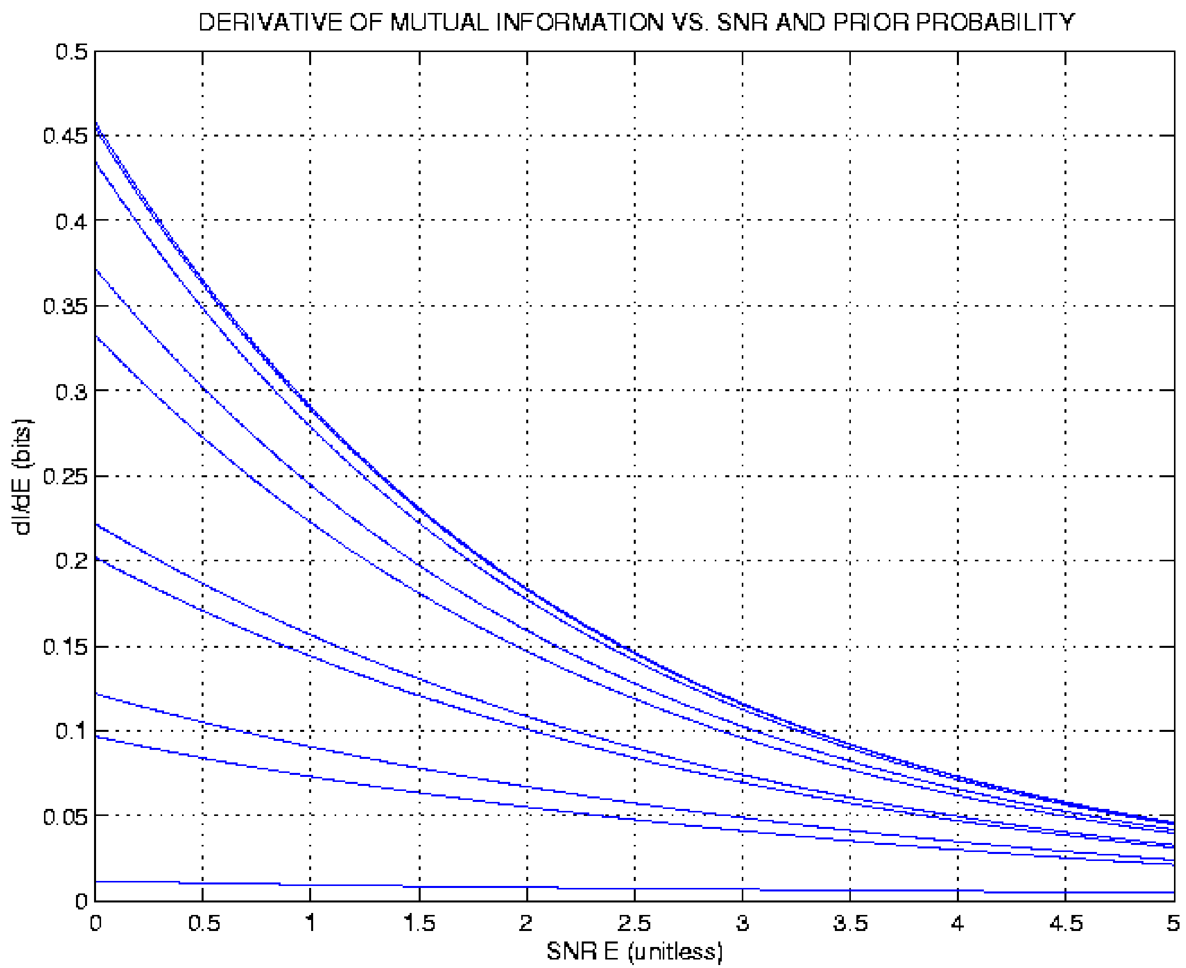
$$\max_{\{E_i\}} \sum_{i=1}^{N} I(X_i, Y_i; p_i, E_i) \quad \text{s.t.} \quad \sum_{i=1}^{N} E_i = E$$

- Kuhn-Tucker conditions:

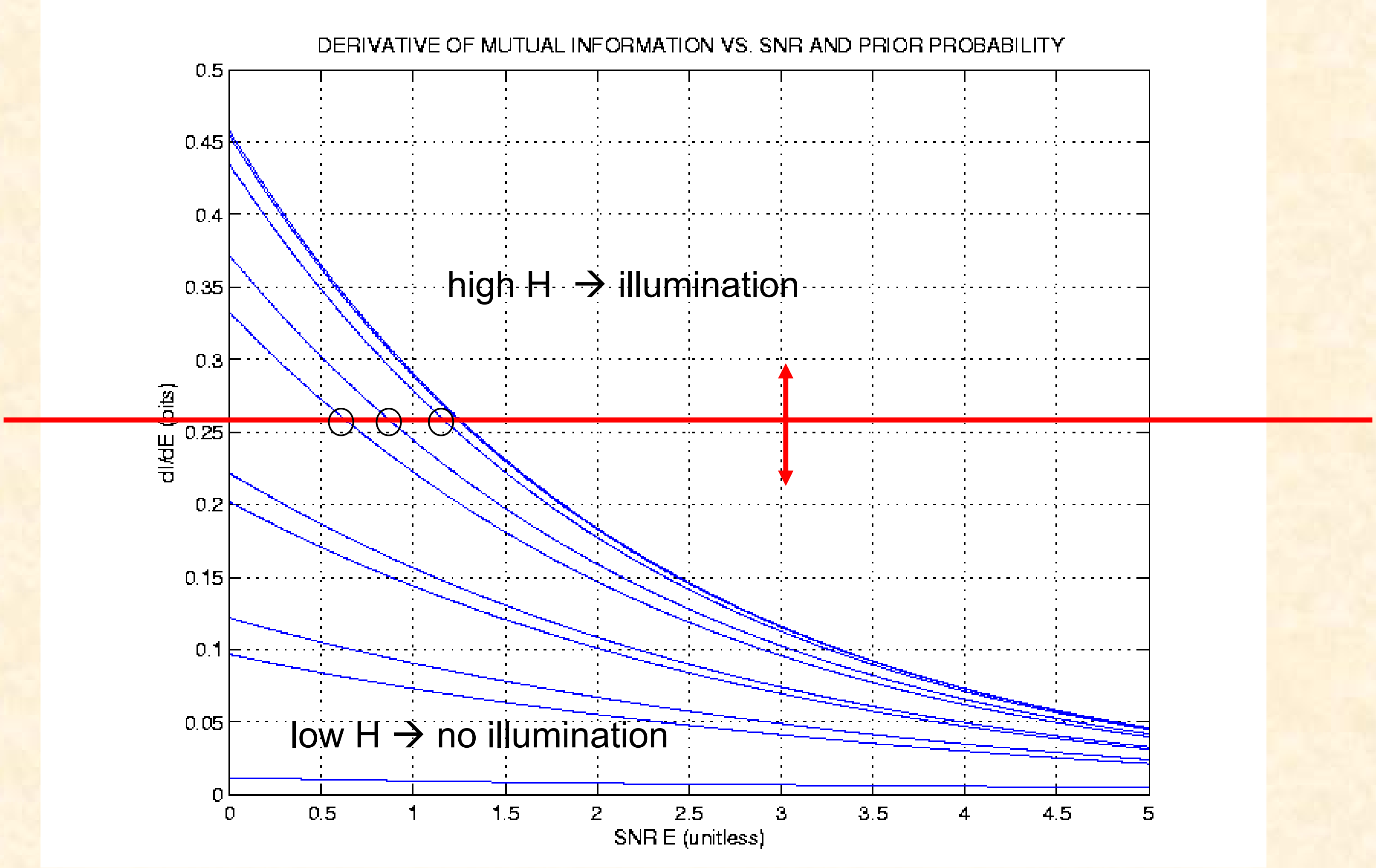
$$\text{If } E_i \neq 0 \,, \quad \text{then } \frac{\partial I}{\partial E_i} = \lambda$$

$$\text{If } \frac{\partial I}{\partial E_i} < \lambda \,, \quad \text{then } E_i = 0$$

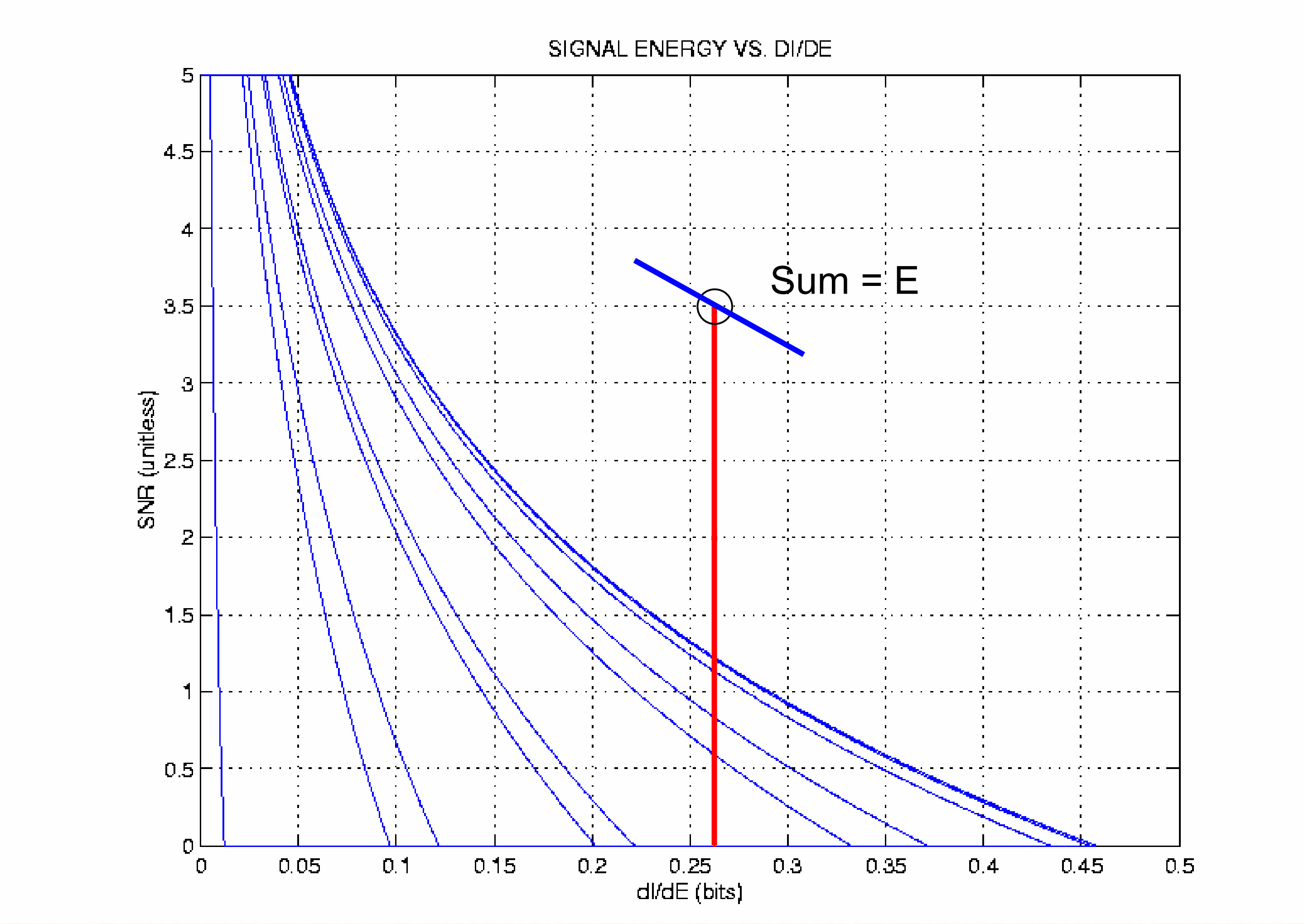
FAMILY OF dI/dE CURVES



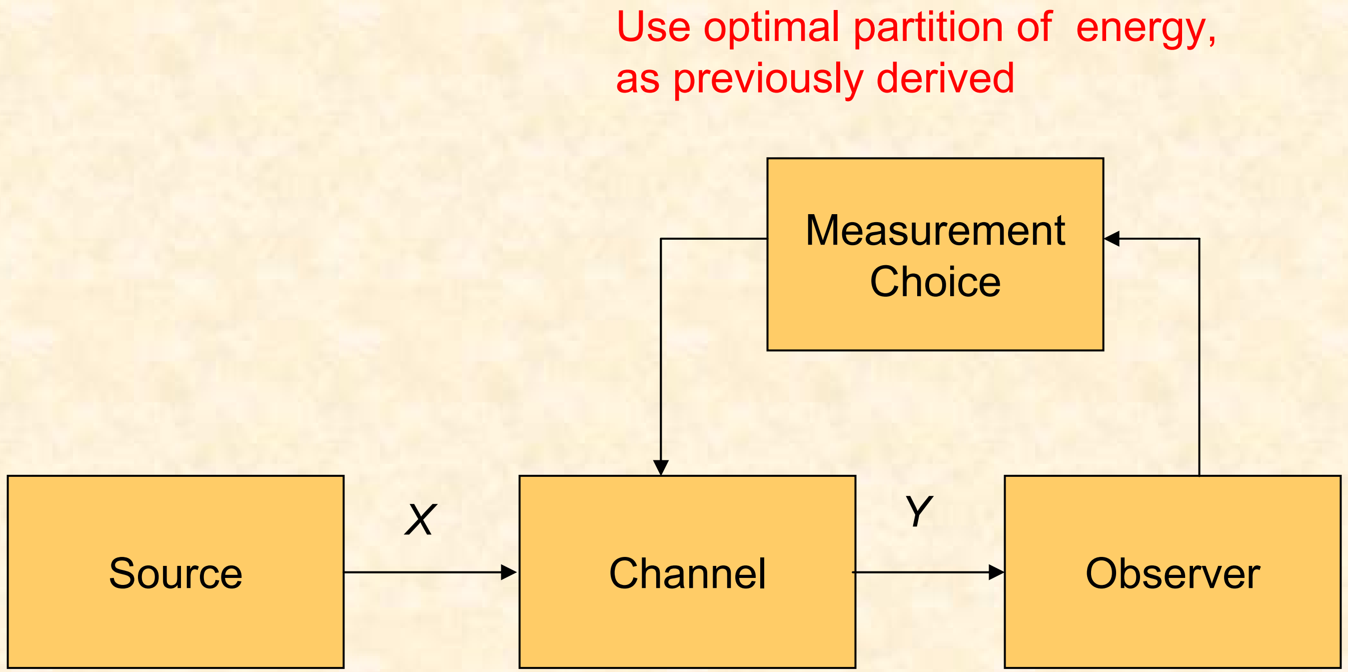
FINDING THE OPTIMAL PARTITION



OPTIMAL PARTITION (ALTERNATE VIEW)

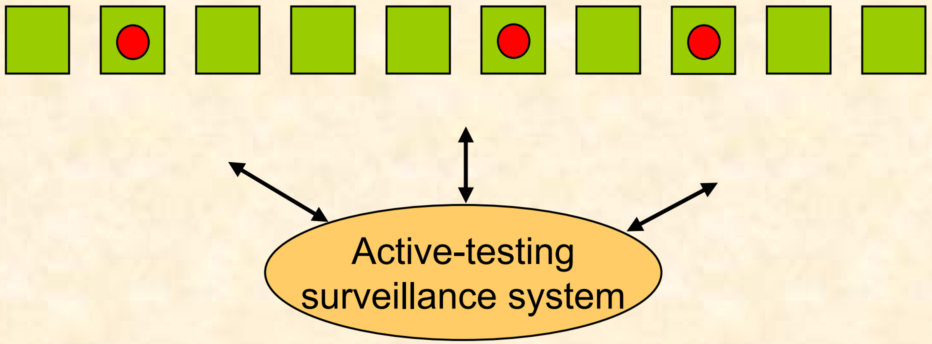


ACTIVE TESTING, AGAIN

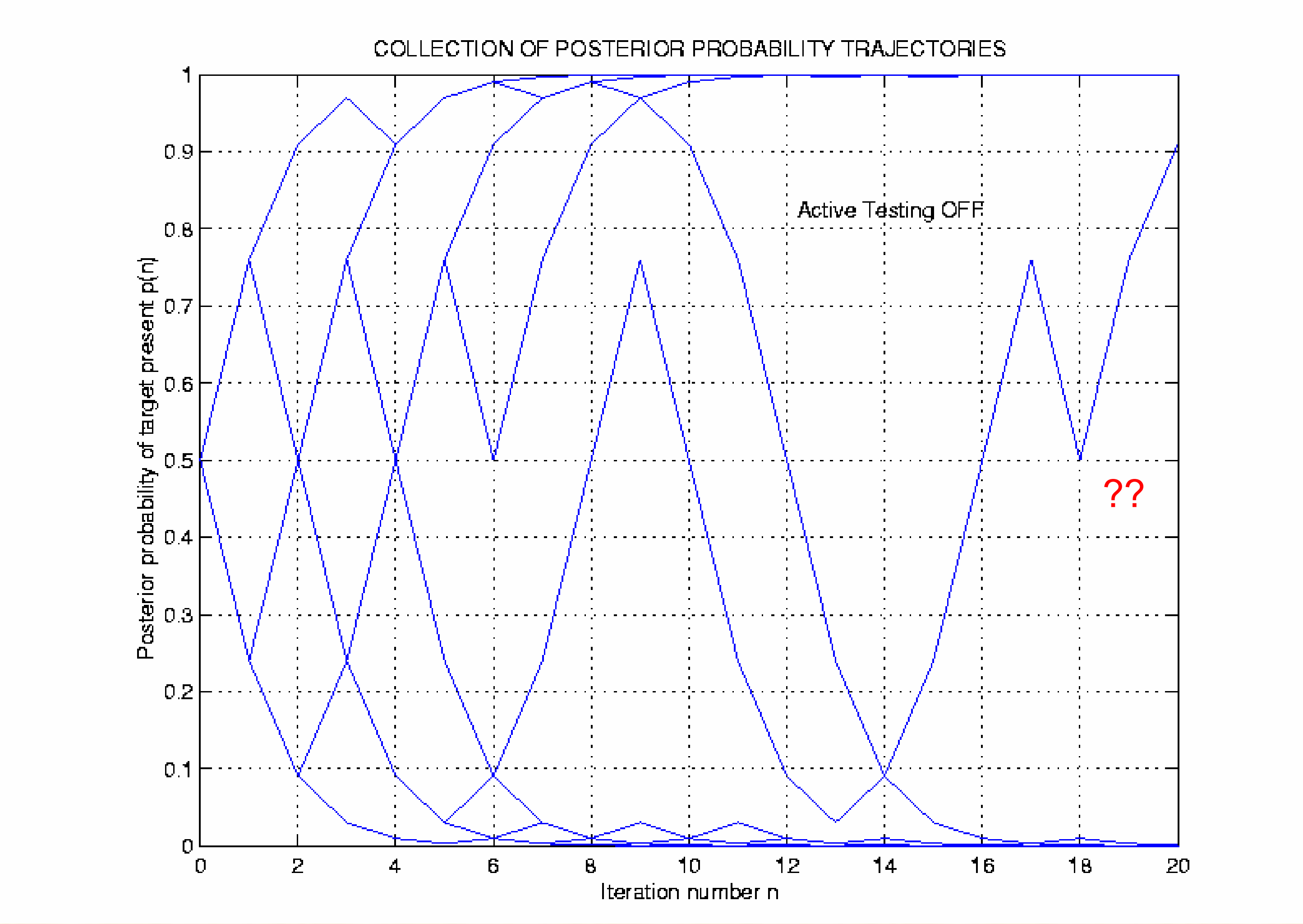


SIMULATION SET-UP

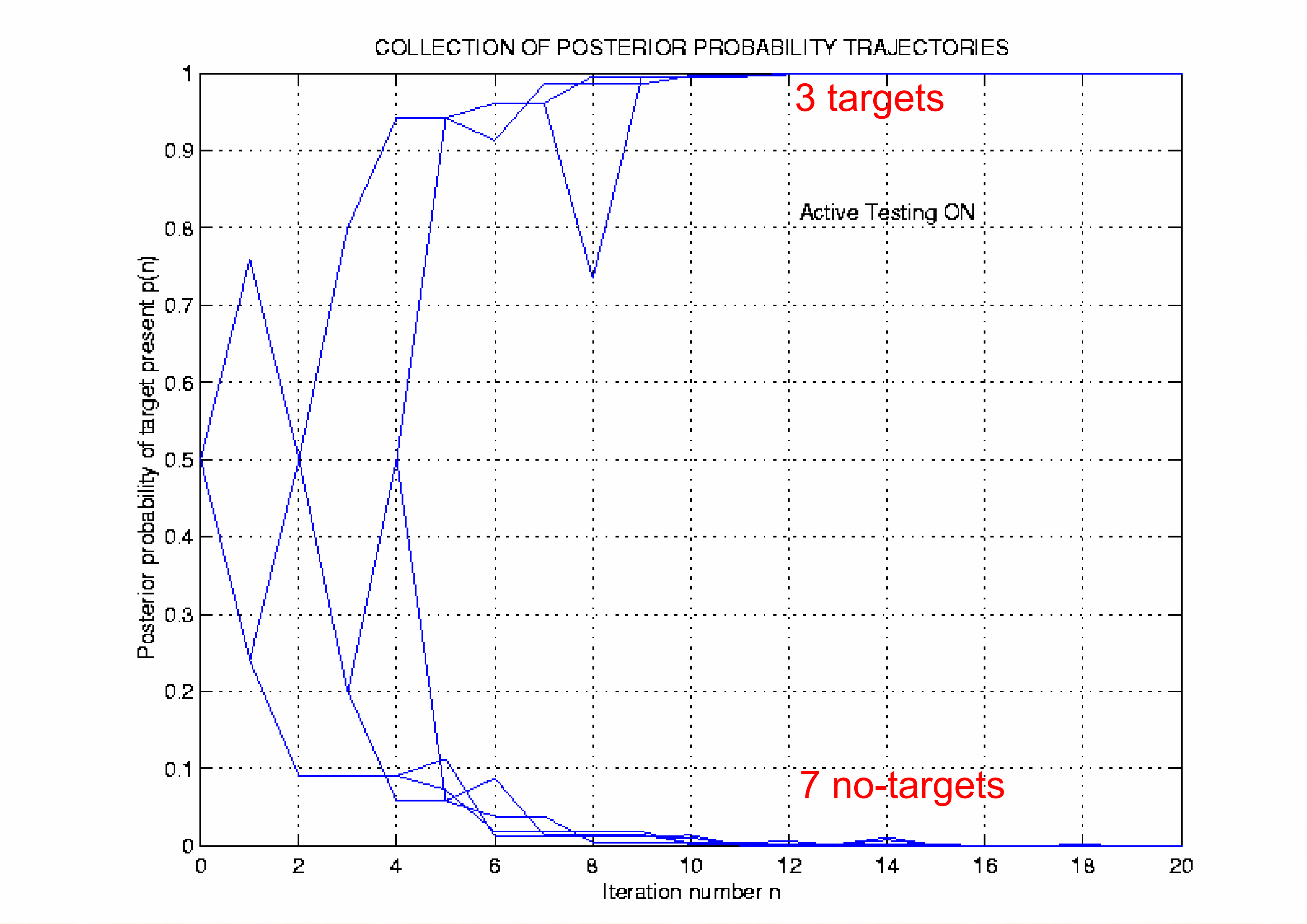
- N = 10 cells
- Total energy E = 5
- 0 dB noise
- Targets in 3 cells
- Prior probability of target present = 0.5, all cells



SEQUENTIAL DETECTION, ACTIVE TESTING OFF



SEQUENTIAL DETECTION, ACTIVE TESTING ON



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RESEARCH AIM

To investigate the feasibility of active-testing surveillance systems in the context of:

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- Ground moving targets (GMTI)
- Multiple targets
- Geographical side information (GIS)
- Platform side information (GPS, INS)

and do it all in Earth-based coordinates.

IMMEDIATE GOALS

- Merge terrain-based radar simulation and active testing
- Incorporate linear constraints in illumination patterns (i.e. beamforming)
- Allow different clutter and target signatures in cell (targets are moving)
- Include adaptive processing for interference

CONCLUSION

We have:

- considered the possibility of Earth-based airborne radar processing
  - advantages
  - disadvantages
  - enabling technologies
- introduced the concept of active-testing surveillance
  - multiple target detection
  - optimization of finite energy resources
  - improved convergence in sequential detection
- indicated future research directions in airborne multisensor pulse-Doppler surveillance radar